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ABSTRACT

A complete petrographic description, particularly of a chemically analysed sample, usually includes a modal analysis (often expressed as per cent by volume). Whilst such micrometric measurements are useful for rocks in which mineral phases do not form by exsolution, they provide limited information of genetic value for granites in which exsolved albite and myrmekite are either attached to primary plagioclase, form in intergranular positions between adjacent alkali feldspar crystals or are held in perthitic intergrowths. In such rocks the difficulty in deciding whether to list the exsolved phases as 'microperthite' or as 'plagioclase' must lead to errors in the recorded feldspar percentages.

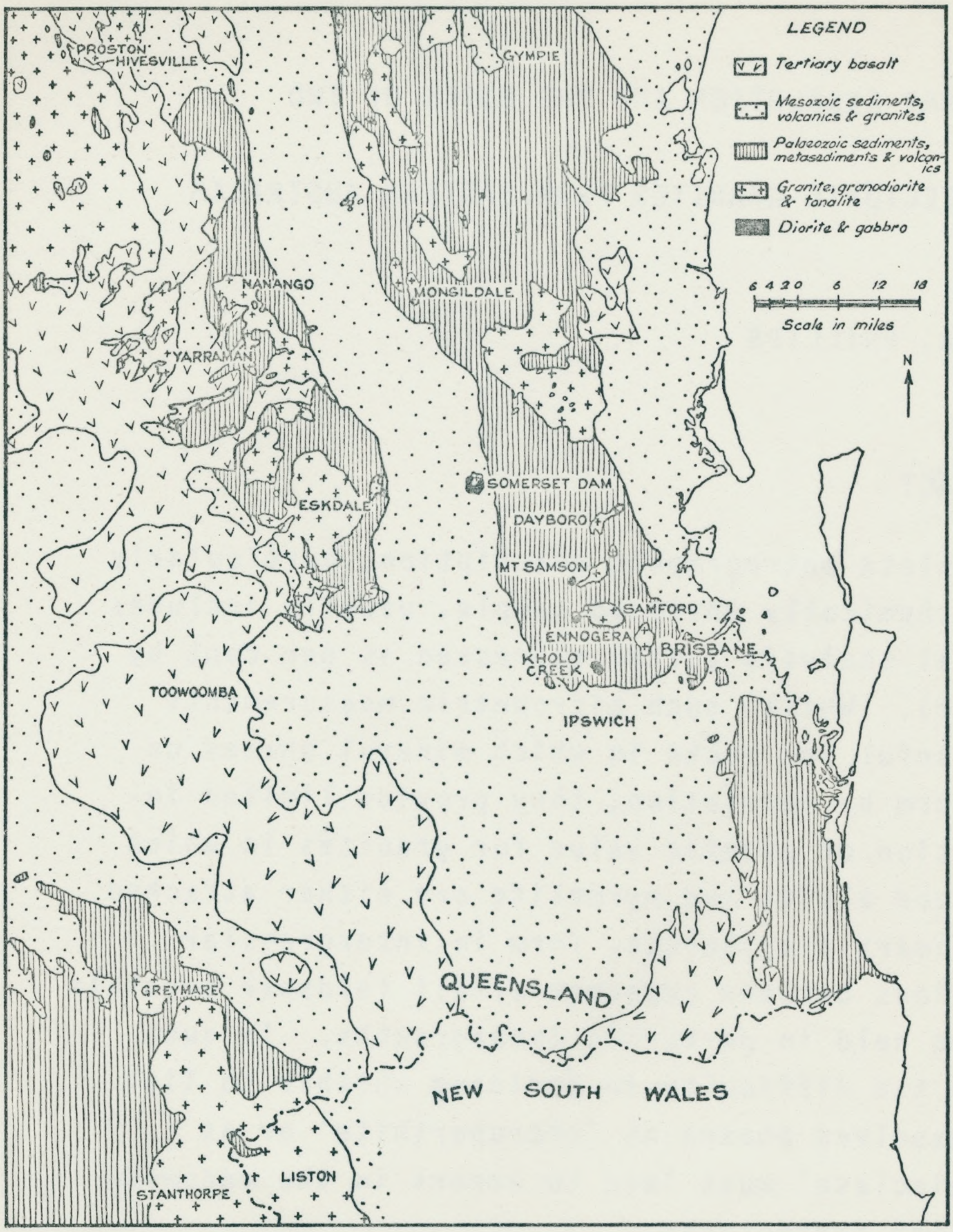

Fig. 1. Sketch map showing the Permian granites of S.E. Queensland and the Stanthorpe region of the New England batholith. The granites discussed in this paper come from near Mt Samson and Liston, as smaller masses than the generalized outcrops shown in this map. Detailed geological sketch maps are given elsewhere (Phillips 1968; Phillips and Tucker 1972). (After Hill and Denmead 1960).

INTRODUCTION

In a recent paper, Parslow (1971) has presented the results of a statistical survey on the variation trends in the mineralogy and major elements of a granite from S.W. Scotland. He draws attention (p.48) to the fact that the observed trends in felsic distributions may be affected by an inherent error in his measurement technique but comes to the conclusion that modal errors (such as recording the perthitic enclosures of albite in microcline as 'microcline', or the placing of rim albite or myrmekite in the mode as 'oligoclase') are insignificant contributors to the felsic regression problem. Parslow (1971) is justified in this conclusion for the techniques he used and the rocks he worked on. However, data listed in this present note indicate that there is some reason for concern over the genetic value of the results obtained using the 'standard' method (by means of a point counter) for the accurate determination of modes of granites. This is because of the tendency for the alkali feldspars to exsolve an albitic phase.

DATA ON TWO GRANITES FROM E. AUSTRALIA

In recent years (Phillips 1968, pp.167-9, 177-8; Phillips and Tucker 1972) I have had the opportunity of studying two very homogeneous, megascopically even-grained granite masses, one (the Ruby Creek granite, Table I, Column 1) a relatively large intrusion from near Liston in the vast New England

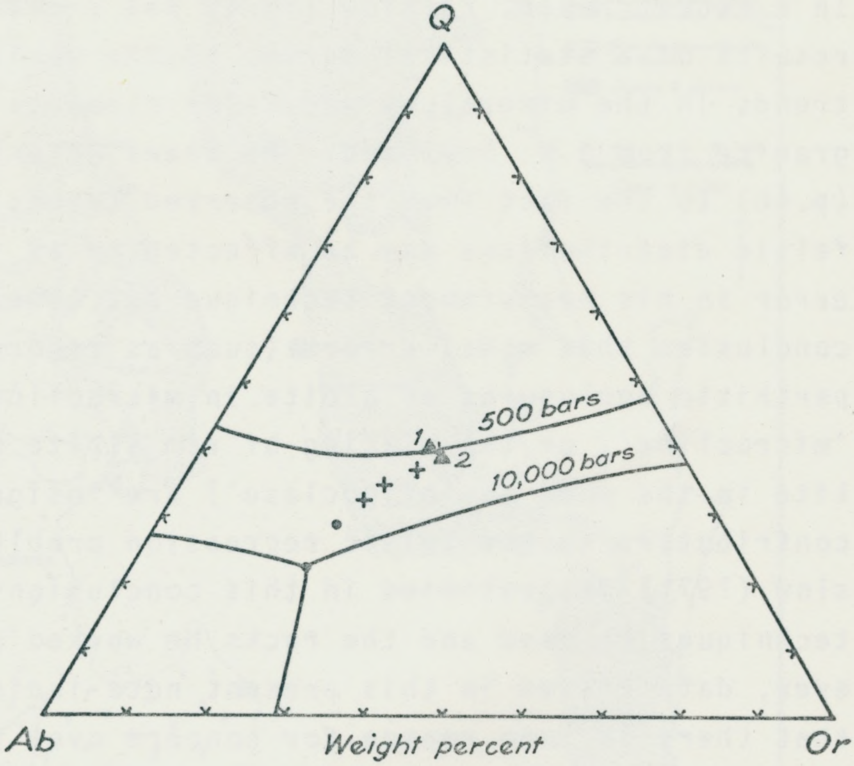

Fig. 2. Compositions of the Ruby Creek granite (1) and the Mt Samson granite (2) plotted in terms of Ab, Or and Q. The plus signs indicade the minima for 500, 1,000, 2,000 and 3,000 bars P_{H_2O} and the full circles represent eutectic points for 5,000 and 10,000 bars P_{H_2O}. (After Luth, Jahns and Tuttle 1964).

batholith in N. New South Wales, and the other (the Mt Samson granite, Table I, Column 2)* a small pluton found near Mt Samson in S.E. Queensland (Fig. 1). The granites, as represented by the samples listed in Table I, are remarkably similar in their chemistry, salic normative properties, plagioclase compositions, colour indices, specific gravity, absolute age and 'average' grainsize. Further, they plot extremely close to the 500 bar minimum in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O described by Tuttle and Bowen (1958) and Luth, Jahns and Tuttle (1964) (Fig. 2). Both general granite regions have very tentatively been considered to be tenuously connected in space and time (Bryan 1923, pp.148-55; Joplin 1962, pp.66-7) although significant differences in the relative sizes of the masses and regional setting are apparent. This matter will be referred to again below.

Dissimilarities between the rocks become evident when their modes (per cent by volume) are examined (Table IIa) and an attempt is made to estimate the number of crystals of each major phase occurring over random linear traverses (Table IIb). The modal analyses were made by the usual optical means using a point counter and the results are based on 30,000 and 15,000 points respectively for rocks 1 and 2, (each represented by one carefully

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* These samples are hereafter referred to as rock 1 (the Ruby Creek granite) and rock 2 (the Mt Samson granite).

selected type hand-specimen)**. Following what is presumed to be a fairly standard procedure (*cf.* Parslow 1971, p.49) rim albite and myrmekite were recorded as 'plagioclase' while perthitic albite and intergranular albite and myrmekite were record-

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** The type specimens were selected only after detailed field studies, the main aim at the time being to obtain representative samples for chemical analysis. As a check on the reliability of using only one type specimen for intensive modal work, four micrometric analyses (roughly 1,000 points each) made separately on different samples over a period of months were averaged. The results are listed in the following table:

MODAL ANALYSES OF SOME SAMPLES OF THE RUBY CREEK GRANITE

	1	2	3	4	5	6
quartz	34.4	34.4	45.8	31.3	36.5	36.5
microperthite	30.6	35.7	24.4	31.6	30.6	30.4
plagioclase	33.2	27.5	26.7	34.2	30.4	30.8
biotite	1.3	2.4	3.1	2.5	2.3	2.0
muscovite, opaque oxide, *etc.*	0.5	-	-	0.4	0.2	0.3

1-4. Different samples of the Ruby Creek granite.

5. Average of samples 1-4.

6. Type sample used in this paper as rock 1 (Table I).

ed as 'microperthite'. There seems to be little alternative to doing this using standard petrographic techniques. It is extremely difficult to differentiate film albite from the host alkali feldspar and virtually impossible to pick between albite forming a primary magmatic outer zone in plagioclase and rim albite of secondary exsolution origin. Checks made some weeks apart gave consistent measurements and the reliability of the results is believed to be at least as good as those obtained by Parslow (1971, Table II). The modal data show marked differences between the feldspar percentages and a notable contrast exists between the mode and norm for rock 2 (even taking into account that the norm is a weight percentage). Volume percentages of quartz and the mafic minerals are similar, and the normative quartz agrees well with modal quartz for both rocks.

The data given in Table IIb were obtained in an attempt to estimate the number of mineral nuclei of the main phases which crystallized as primary grains from a presumed magmatic state. These results are not very satisfactory. It became obvious that it was possible, due to irregular grain shapes, to record the same crystal more than once in a continuous linear traverse past the intersection of the microscope ocular cross-hairs, and it was also difficult to decide if inclusions were part of an external phase recorded as a separate grain. The overall picture, however, seems clear. The total number of grains for each rock is similar (reflecting comparable grainsize) as are the aggregates of the quartz and biotite crystals. A contrast appears again in the feldspar numbers.

In rock 1 plagioclase grains dominate microperthite crystals whereas in rock 2 microperthite grains outnumber plagioclase. The procedure of attempting these estimates emphasized the fact that accurate grainsize measurements, even in granular rocks, are extremely difficult to obtain and in this note grainsize is treated only in a general way.

TEXTURAL OBSERVATIONS ON BOTH GRANITES

The data given above suggested that the textures of both rocks be looked at more closely and some of the observations made in detail elsewhere are noted here (Phillips 1968; Phillips and Tucker 1972). Since textures may rarely be measured precisely, the results recorded below (carried out on about forty thin-sections) are made only in a general way and may be subject to personal opinion. However, an attempt has been made to form an impartial analysis.

Rock 1 overall does not have a marked microperthite development and appears to be somewhat depleted in film perthite as compared with rock 2. Plagioclase grains are more numerous in rock 1 and this feldspar is well-developed and a little coarser (up to 3 mm) than in rock 2. Distinct albite rims are found in rock 1 reflecting a greater boundary contact with alkali feldspar than in rock 2.

Rock 2 contains microperthite with relatively coarse albite veins and well-formed long and numerous albite films repeating at close intervals. Rim albite, although present, does not appear to be as common as in rock 1 because of the lower number of plagioclase grains available as seed crystals for secondary growth. In rock 2 a distinct tendency exists for microperthite grains to aggregate together. Such an agglomeration of alkali (potash) feldspar crystals provides a large, although somewhat irregular, grain boundary surface for the location of intergranular albite and it is in such a position that a significant percentage of exsolved albite is held in rock 2. [It is here that grainsize becomes an important factor. A single large alkali feldspar need not, on exsolution, contain as much albite of the intergranular type as would occur in an alkali feldspar crystal aggregate of equal volume (a more stable arrangement than albite held in perthitic arrangement (Ramberg 1962)). An aggregate of smaller grains would probably hold exsolved material within the *original* volume of the initial high-temperature alkali feldspar along the grain boundaries. The tendency in the case of a large single alkali feldspar might be for the albite to exsolve 'externally' to adjacent plagioclase and hence be counted as 'plagioclase'. Abundant finer grained seed plagioclase crystals located next to such an alkali feldspar would attract significant amounts of albite.]

DISCUSSION

Let us suppose that a link does exist between both granite masses as was suggested elsewhere (Bryan 1923; Joplin 1962) and that we are dealing with essentially the same granite magma or at least two magmas very similar in composition and in time of emplacement. Both rocks plot close to the 500 bar minimum of Tuttle and Bowen (1958) suggesting that they rose to high crustal levels. The much larger mass of rock 1 might have caused it to cool over a longer time interval than that needed by the very small pluton represented by rock 2, and hence each rock may now represent the result of different cooling rates of the same or similar magma.

The questions now arise: is this a reasonable supposition and, if so, does the measurement of the mode help to elucidate the problem of the cooling history of the granites, i.e. does the mode have any critical genetic significance? Having regard to the general disposition of the masses, their chemical properties and their ages, the initial assumption, whilst very speculative, is not grossly improbable. One would then like to think that the mode of each granite has some genetic value (such as indicating roughly rates of cooling) and it surely must be a guide for such information. The mode combined with the number of suggested primary crystal nuclei indicates that more crystals of alkali feldspar developed for rock 2 and that these nuclei subsequently survived cooling as a relatively high amount of microperthite. (Textural features also indicate that the early alkali feldspar crystals agglomerated together.) But is the mode an *accurate* measure of such an arrangement?

There can be little doubt that the 'standard' technique of determining a mode as outlined above must affect its ultimate genetic value. Exsolution of albite together with the position to which it exsolves, whether as rims, as intergranular patches or as lamellae in perthite, must bias the measurement of the mode. Overall there seems little doubt that for rock 1 a greater tendency existed for the albite to be 'freed' from the initial high-temperature alkali feldspar boundaries and hence be added to plagioclase than for rock 2, and in this manner it must affect the measured amount of modal 'plagioclase'. Similarly it appears that much of the albite in rock 2 is held within the alkali (i.e. potash) feldspar in perthitic arrangement or along intergranular boundaries and is recorded as 'microperthite'. Thus an initial tendency to have either the primary plagioclase or alkali feldspar volumetrically dominant (as suggested by the count of crystal nuclei) is compounded by the later effects of exsolution.

Is there any justification in grouping together various distinct generations in feldspar and simply listing them as 'plagioclase' or 'microperthite' and then performing various statistical analyses on the results? The data presented in this paper (always accepting that the magmas are of similar origin) might suggest that some caution be used in the assessment of a modal analysis of a granite. Certainly in a rough way the mode has value especially in regard to the differentation between hypersolvus and subsolvus granites as illustrated by Tuttle and Bowen (1958). However, unless an attempt is made to obtain a measure of the exsolved albite (and myrmekite) in a rock errors must arise. What amount of exsolved material has contributed to the disparity in the modes listed in this paper, and what is truly the genetic volumetric relationships between the initially crystallized higher temperature feldspars and the present relationships of the feldspars as seen after exsolution? The writer cannot answer these questions with any certainty.

A secondary consideration in this discussion is the effect that modal data have on the classification of a granite. Following most commonly accepted definitions based on feldspar/feldspar ratios of $^1/_3$ or $^2/_3$, rock 1 could well be called an adamellite yet all its other features point to it being a granite *sensu stricto*. Even rock 2 just fits into the adamellite category. This conflict suggests that for some granites modal criteria used to determine their name may be rather arbitrary, somewhat artificial and a little misleading.

This study is only preliminary in nature and would be of greater use if applied to a larger number of closely allied plutons sampled over a wider area or based on the investigation of one chemically homogeneous mass in which detailed fabric observations are linked with accurate field mapping. Nevertheless the data noted here may stimulate further thought on the rather complex problem of the accurate determination of granite (and syenite) modes and their significance.

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TABLE I - COMPARATIVE DATA ON

Chemical Analyses	1	1a	2
SiO_2	76.07	76.52	76.18
TiO_2	0.10	0.07	0.14
Al_2O_3	13.11	12.73	12.45
Fe_2O_3	0.18	0.48	0.95
FeO	0.87	0.62	0.78
MnO	0.04	0.12	0.02
MgO	0.12	0.14	0.22
CaO	0.66	0.75	0.69
Na_2O	3.49	3.58	3.38
K_2O	4.58	4.59	4.88
H_2O+	0.43	0.37	0.39
H_2O-	0.20	0.17	0.08
P_2O_5	0.10	0.02	0.10
CO_2	n.d.	0.04	n.d.
	99.95	100.20	100.26

CIPW Norms	1	1a	2
Q	36.31		36.04
or	27.07		28.94
ab	29.53		28.84
an	2.62		2.50
C	1.45		0.61
hy { en	0.30		0.50
of	1.36		0.40
mt	0.26		1.38
il	0.19		0.30
ap	0.23		0.34
H_2O	0.63		0.47
	99.95		100.32

TWO GRANITES FROM E. AUSTRALIA

	1	2
Normative An	8.15	7.98
Plagioclase compositon core	An_{16}	An_{20}
(measured $\perp x$) 'average'	An_{10}	An_{12}
rim	An_{0}	An_{0}
Normative Or + Ab + An	59.22	60.28
Normative Q + Ab + Or	92.91	93.82
Colour Index	2.3	2.0
Specific Gravity	2.63	2.63
Absolute age by K-Ar method	225 m.y.	217 m.y. approx.
'Grainsize'	0.5-2.0 mm	0.5-2.0 mm

1. The Ruby Creek granite (a biotite leuco-(adamellite)-granite) from near Ruby Creek about 7 km W.N.W. of Liston, N.E. New South Wales (Phillips 1968, Table 2, analysis 15). Liston is situated some 150 km S.W. of Brisbane. In earlier work (Phillips 1964, 1969 (written in 1965)) this rock was referred to as the Ruby Creek Adamellite. Analyst, J.R. Dickson.

1a. The 'Sandy Granite', an analysis taken from rocks sampled over a wide area (Saint-Smith, 1911). This rock is the Ruby Creek granite and the analysis has been included to show the close similarity to analysis 1, taken from a single hand-specimen.

2. Granite (a biotite leucogranite) from Mt Samson, S.E. Queensland (Phillips and Tucker 1972, Tables 1 and 2, Column 6). Mt Samson is situated some 30 km N.N.W. of Brisbane. Analyst, J.R. Dickson.

TABLE IIa - MODAL ANALYSES OF THE GRANITES

	1	2
quartz	36.5	34.9
microperthite	30.4	40.1
plagioclase	30.8	23.0
biotite	2.0	1.7
muscovite opaque oxide, *etc.*	0.3	0.3
	100.0	100.0

TABLE IIb - NUMBERS OF CRYSTALS MEASURED OVER A LENGTH OF 40 CENTIMETRES

	1	2
quartz	281 (37.2%)	261 (33.8%)
microperthite	173 (22.8%)	281 (36.4%)
plagioclase	265 (33.1%)	198 (25.7%)
biotite	37 (4.9%)	33 (4.1%)
	756 (100.0%)	773 (100.0%)